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**Evaluation of
Alternate Fuels for
Supply Boats**

Arthur D Little

**Submitted for the
Minerals Management Service**

**By
Arthur D. Little, Inc.**

May 24, 1990

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1.0 BACKGROUND AND SUMMARY

1.1 Introduction

The Minerals Management Service of the Department of the Interior is formulating a long-term technology program to develop advanced NO_x control techniques for offshore oil and gas operations. Implementation of effective NO_x control measures could assist in improving the air quality impacts associated with California offshore development programs. This technology program will provide funding for those technologies which are likely to be successfully demonstrated within five years and will have a significant impact on NO_x emissions. The program will also monitor promising technologies which might offer attractive long term emission benefits, but are unlikely to be demonstrated within five years.

Arthur D. Little, Inc. has been assisting the Minerals Management Service in the development and implementation of its NO_x control program. As part of this effort, the Minerals Management Service commissioned Arthur D. Little, Inc. to evaluate the use of alternate fuels on supply boats. The possibility of using alternate fuels on supply boats has been suggested in several forums. Three alternate fuels have been suggested: Methanol, Compressed Natural Gas (CNG), and Liquefied Natural Gas (LNG). Many concerns about using these fuels on marine vessels have been raised. The objective of this report is to identify and describe these concerns and their basis. Our findings are documented in this report which is organized as follows:

- Section 2: Reviews alternate fuels technology and present case studies of selected alternate fuel conversion programs.
- Section 3: Presents emission levels from diesel engines converted to alternate fuels.
- Section 4: Describes safety regulations and concerns related to the implementation of alternate fuels on supply boats.
- Section 5: Describes vessel design and operation parameters which would be affected by using alternate fuels.
- Section 6: Provides an overview of the availability and price of alternate fuels.
- Section 7: Describes other institutional concerns relating to the use of alternate fuels on supply boats.

1.2 Summary

Many sources have described various safety, vessel cost, and institutional barriers to the use of alternate fuels in supply boats. The purpose of this assessment is to identify and evaluate these various barriers. Our findings are summarized below:

Alternate Fuels Technology: Alternate fuels technology has not been demonstrated on supply boat type engines operating on a marine duty cycle. As a result, the status of the technology must be inferred from its developments for other applications. Methanol engine technology is being proven for highway applications. Although certain technical problems have occurred, it appears that research and development will solve them. Methanol technology, however, is oriented toward highway engines, not larger supply boats. The same techniques which are being developed for methanol highway engines would need to be transferred to supply boat engines. Low emission natural gas technology is well-proven for stationary engine applications operating on a constant speed duty cycle. Similar technology is being developed, but not yet proven, for large engines which operate on a variable load and speed duty cycle. Preliminary tests on railroad locomotive engines (similar to supply boat engines) show initial promise, although considerable development is still required.

Engine Emissions: One barrier or concern is that the emission benefits of methanol or natural gas are not clear and simple --- they depend on the engine design and operation and ultimately, how the fuel is burned. Marine engines for supply boats may present operational limits to certain options for CNG or methanol retrofit. There are many different design configurations to introduce an alternate fuel in a diesel engine. Different injection and ignition techniques can produce substantially different emissions. With proper engine design, both methanol and natural gas can be used in dual fuel (i.e., combined with diesel fuel) or dedicated (100% alternate fuel) engine configurations. In general, the dual fuel configurations provide less emission benefits compared to the dedicated options. Present diesel engine technology can produce about 7 to 9 grams NO_x per horsepower hour, with diesel fuel, depending on the specific model, the injection settings, and other factors. Dual fuel techniques (with either methanol or natural gas plus diesel) can be expected to produce about 3 to 6 grams NO_x per horsepower hour, with diesel fuel, depending on the specific model, the injection settings, and other factors. Dedicated methanol and natural gas engine technologies can be expected to produce 1-3 grams NO_x per horsepower hour, according to test data. However, the advantages of having a marine engine which offers the flexibility of being able to switch over to diesel fuel are many, thus favoring the dual fuel configuration. Finally, aldehyde emissions from methanol and elevated HC emissions from low NO_x natural gas engines are also concerns.

Safety: Both natural gas and methanol pose safety hazards for marine vessel operations. The most significant hazards are those of flammability and methanol toxicity. A confined release of either fuel within the hull would pose a serious threat to crew safety. Other

hazards exist in the refueling operations. While standards and regulations are available for onshore uses of alternate fuels, no such standards have been developed for marine applications. As a result, the first alternate fuel conversions will have to rely on other standards and guidelines. This will pose a challenge to classification agencies and insurers for any alternate fuel vessel.

Vessel Design and Operation: Both natural gas and methanol have poorer energy storage density than diesel fuel. As a result, vessels will face a weight and space penalty for converting to an alternate fuel. This penalty is quite severe for compressed natural gas. Any boat which is converted to either fuel will most likely have to operate within one geographic location.

Fuel Supply and Infrastructure: Methanol's existing supply network is established for its use as a chemical feedstock. Large-scale penetration of methanol into the fuels market could quickly reduce the global oversupply of methanol capacity. Methanol fuel can be expected to cost from 50 to 150 percent more than diesel on an energy equivalent basis. Natural gas, although not widely used as a transportation fuel, has a well-developed distribution system. Also, many oil projects which use supply boats also produce natural gas, which, after processing, could be used for the boats. If so, CNG might cost 30 - 40 percent less than diesel fuel; if not, the price of compressed natural gas fuel would be 20 to 60 percent more than diesel fuel.

Other Institutional Considerations: Owing to the large expense in converting a supply boat to an alternate fuel as well as the relatively poor financial position of the vessel industry, financing for such a project might pose a difficulty. It is possible that oil companies operating offshore projects would have to provide a financing mechanism for a conversion and demonstration program.

2.0 ALTERNATE FUELS TECHNOLOGY FOR MARINE VESSELS

A number of previous laboratory and in-field projects have examined alternate fuels for application to diesel engines. Most of these projects utilized heavy duty highway diesel engines; relatively little work has been accomplished for larger marine application diesel engines. This section describes the different approaches that have been used for methanol and natural gas on all types of diesel engines. It also describes experience in the application of alternate fuel technologies to large in-field diesel engines that are similar to those encountered in marine applications.

2.1 Engine Technology

The use of either methanol or natural gas in a diesel engine requires modifications which can range from relatively minor adjustments to complete engine redesigns (i.e., fuel-specific engine substitution). The modifications required, along with the associated performance and the emissions' benefits for both methanol and natural gas, are discussed in the following sections.

2.1.1 Methanol

Methanol does not ignite upon compression as readily as diesel fuel ignites. As a result, the conversion of a diesel engine to methanol fuel must include some form of ignition enhancement. Five techniques have been used to convert diesel engines to methanol operation:

- Glow plug operation,
- Diesel pilot operation,
- Fuel ignition improver additives,
- Conversion to spark operation, and
- Elevated compression ignition.

Each of these techniques is described below.

Glow Plug Assisted Ignition

A hot surface ignition source can ignite methanol fuel in a diesel engine. This ignition technique takes advantage of the low surface ignition temperature of methanol. A metal coated rod, connected to a voltage source and inserted into the combustion chamber, ignites the fuel. This device, called a glow plug, is also used on some diesel engines to facilitate cold starting.

Problems associated with this technique are glow plug life and completeness of fuel combustion. Techniques for creating more complete combustion involve redesigning the

fuel injectors, the piston bowl, and/or the cylinder head. Extending the life of the glow plugs can be accomplished by using ceramic materials, although glow plug expected service life beyond 1,200 engine hours is uncommon.

Ignition Enhancers

The addition of specially formulated compounds to methanol fuel can allow for ignition of the fuel by only the compression normally encountered in a diesel engine. This technique results in minimal engine modifications. The amount of additive needed is a function of the compression ratio of the engine and the additive formulation. Additive rates between 3 and 8 percent by weight are common. The required engine modifications increase the capacities of the fuel delivery and injection systems. Ignition enhancers are rather expensive. Although the additive rate is only a few percent, the enhancers substantially increase the effective fuel price.

Diesel Pilot Ignition

Mixtures of diesel fuel and methanol with over 30 percent methanol have exhibited poor performance on compression ignition engines. Successful tests have been conducted, however, running on methanol fuel with diesel fuel being separately injected into the combustion chamber. This technique is called methanol with a diesel pilot. Essentially, the DF2 ignites first and this flame ignites the methanol.

This type of conversion involves arranging two fuel delivery and injection systems on the engine: one for the methanol and one for the diesel. With this technique, the methanol substitution on an energy content basis can be as high as 90 percent.

Conversion to Spark Ignition (Or Engine Substitution)

Substitution of a spark ignition engine designed for methanol is a straight forward but relatively expensive approach. There are literally millions of alcohol operated engines in use today. Alternatively, converting a diesel engine to spark operation involves major modifications to the engine, including changes to:

- cylinder heads,
- pistons,
- valves, valve seats, valve guide seals,
- camshaft,

- intake manifold, and
- fuel system.

The fuel can be introduced either by a completely new injection system (higher volume of fuel per stroke) or by carburetion. Addition of an ignition system, including coils and a distributor, is also required. Fuel consumption generally suffers with this option.

General Methanol Considerations

Table 2.1 is a comparison of the properties of diesel and 100 percent methanol. Methanol produces only about 44 percent as much energy per unit volume as diesel when combusted. Converting a diesel engine to methanol requires a much higher flowrate of fuel. As a result, methanol engines require a higher capacity fuel delivery system and a larger fuel storage tank when compared to diesel engines of equivalent power output and operating range. Because of the higher heat of vaporization, methanol cold starting can be difficult, especially for spark ignited engines.

Methanol has lower viscosity and lubricity characteristics than diesel fuel. This requires that either a lubricant be added to the fuel or that engine lubricating oil be directed to the fuel pump and injectors. Lubricating additives include about 1 percent by weight of castor oil. This favors carburetor-type designs.

Methanol is also quite corrosive. Therefore, a corrosion inhibitor, such as morpholines at 0.02 percent by volume is generally added to the fuel. Stainless steel tubing and anodized aluminum are the recommended materials of construction for the fuel tank end delivery system.

There are no problems of note with using methanol in a spark ignition engine designated for methanol. Mechanical problems encountered with the use of methanol in converted diesel engines have included the following:

- Increased wear of the fuel delivery system due to the higher volume throughput required;
- Corrosion and wear problems of the fuel delivery system due to the low viscosity and poor lubricity associated with methanol;
- Formation of deposits in fuel injectors and other fuel system locations;

TABLE 2.1
FUEL PROPERTIES

<u>PROPERTY</u>	<u>UNITS</u>	<u>METHANOL</u>	<u>GASOLINE</u>	<u>2D DIESEL</u>	<u>CNG</u>	<u>LNG</u>
SPECIFIC GRAVITY	KJ/KG	0.79	0.75	0.85	0.16*	0.424
HEAT OF VAPORIZATION	KJ/KG	1110	430	660	0	510***
LOWER HEAT OF COMBUSTION	KJ/KG	19700	43961	42550	47700	47700
VOLUMETRIC ENERGY CONTENT	KJ/L	15600	33000	36200	7630*	20200
RELATIVE VOLUME REQUIRED FOR EQUIVALENT ENERGY	FUEL/DIESEL	2.32	1.1	1	4.74*	1.8
STOICHIOMETRIC A/F RATIO		6.4	14.9	14.6	17.24	17.24
BOILING POINT	oC	65.6	171(90%)	304(90%)	-164	-164
IGNITION LIMITS		3.0-0.50	2.5-0.68	na	1.25-0.44	1.25-0.44
SURFACE IGNITION TEMPERATURE	oC	904	1004(iso)	na		
AUTOIGNITION TEMPERATURE	oC	478	300-450	315	1000	1000
RESEARCH OCTANE NUMBER		106	92	na	130	130
CETANE NUMBER		3	8-14	40-45		

* at 3000 psig

** Natural gas assumed methane

*** This is actually the enthalpy required to heat the fuel

- Cracking of pistons and cylinder walls due to thermal stress induced by the high heat of vaporization and increased fuel volumes. An order of magnitude more energy is required to vaporize methanol than is required for diesel fuel;
- The lack of soot in a methanol engine causes engine lubricating oil additives to form deposits on pistons and valve seats, increasing wear; and
- Rapid exhaust valve clearance wear due to engine lubricant oil deposits.

The above problems are not considered insurmountable. Ongoing methanol engine development programs are solving these problems by using fuel additives, testing low ash engine lubricating oils, and redesigning pistons and valve seats.

2.1.2 Natural Gas

Natural gas engine technology for marine vessels would need to be based on either stationary spark ignited or dual fuel natural gas engine (low emission) technology (converted to marine duty) or from marine diesel engine technology converted to natural gas (dual fuel). Low emission stationary natural gas engines are designed for constant speed, variable load duty cycles. This technology could be used directly only in vessels equipped with an engine generator power train.

Natural gas has the ability to self-ignite in a diesel engine at 10 - 12 compression ratio, although not reliably. In fact, retrofit is a problem because many 400 - 1200 hp diesel engines have compression ratios in the 14 -20 range so that natural gas pre-ignites. Heavy duty highway diesel engines used in transit buses and trucks have been converted to natural gas. Some experience also exists for large diesel engines normally used in locomotive and marine service, but this experience consisted of exploratory feasibility tests.

There are essentially three methods for introducing the natural gas to the combustion chamber:

Injection at or near top dead center involves compressing natural gas to a pressure between 3,000 and 5,000 psi. This injected gas ignites and burns as a jet just like diesel fuel spray, and this produces relatively high NO_x . The high gas injection pressure allows the necessary quantity of fuel to be introduced into the cylinder in the short amount of available time. High compression ratios and efficiencies result from this technique. This technique can be used on either 2-stroke or 4-stroke engines. Wartsila produces engines of this type specifically for LNG marine transport vessels.

Caterpillar, Inc. is currently involved in a project to demonstrate a glow plug assisted, direct-injected natural gas engine with specific power output and thermal efficiency equal to a diesel engine. Demonstration of the technology on a Caterpillar 3400 series single cylinder test engine has achieved specific power and thermal efficiency improvements of 50 percent and 13 percent, respectively.

The design incorporates the injection of natural gas at about 2800 psig through an injector inserted into the diesel injector port, compression ratio of 16:1 and a glow plug assisted ignition. Power input to compress the gas is estimated at 8 percent of engine output with a gas delivery pressure of 10 psig. The project intends to test the techniques on a 3500 series single cylinder engine and then produce a multicylinder engine for qualification and field tests by the end of 1991.

Only minimal emissions testing has been conducted on the single cylinder 3400 engine. Emissions of NO_x are indicated to be 6.0 grams/hp-hr and HC are 0.1 grams/hp-hr. Lower emissions are expected with the use of injection/combustion system modifications and catalysts.

Injection of gas during the compression stroke following the close of the intake valve and prior to ignition requires that the gas be compressed to only moderate pressures (8 to 10 volumetric compression ratio). The gaseous fuel is typically injected through valves in the cylinder head or through ports in the cylinder liner. Due to the tendency of natural gas to pre-ignite and cause high cylinder pressures, compression ratios must be reduced and/or ignition timing retarded to prevent damage to the engine. This causes a decrease in engine efficiency compared to a diesel engine and is a disadvantage of this type of fuel introduction technique.

Introduction of the gas through the intake manifold, or essentially a carburetor, is the most popular method of natural gas conversion on 4-stroke highway diesel engines. This technique has even greater performance disadvantages than injection during compression, yet is a proven technique to convert 4-stroke highway diesel engines to spark ignition/natural gas fuel.

The techniques used for igniting natural gas mixtures in a diesel engine include:

- Dual fueling,
- Spark conversion, and
- Glow plug operation.

Each of these are described below.

Dual Fueling

Dual fueling involves injecting diesel fuel into the combustion chamber to promote ignition due to compression, as in a diesel engine. This requires two separate fuel delivery systems: one for natural gas and one for the diesel pilot. Dual fueling of large stationary engines is considered an established technology for two and four-stroke engines, utilizing the injection-during-compression method of fuel introduction.

Dual fueling utilizing high pressure injection close to top dead center has been investigated by Southwest Research Institute on a two cylinder EMD-567B locomotive test engine. High pressure injection is best utilized on larger diesel engines due to their lower RPM, thereby allowing more time for fuel introduction. These tests showed that up to 98 percent natural gas substitution on an energy basis was possible with reliable ignition. Problems that needed to be overcome were mostly related to optimizing the mixing and DF2 pilot injection. These problems prevented operation at low loads and required relatively fuel-rich mixtures, thereby producing a somewhat lower thermal efficiency than a comparable diesel engine.

Spark Conversion

The conversion of a diesel engine to spark ignition will allow for the use of natural gas. This conversion is similar to that for methanol fuel. Introduction of the fuel by the carburetion and injection-during-compression methods has been demonstrated. A number of 4-stroke highway diesel engines have been converted to spark ignition with carburetors for demonstration tests.

Gas engines which use spark ignition and carburetion with turbocharging and aftercooling are standard practice in the stationary engine market. Both Waukesha and Superior market engines of this type ranging in size from 500 to 2,500 bhp. These engines utilize a prechamber ignition system which provides for efficient ignition at leaner conditions, thereby reducing emissions and fuel consumption. These engines are designed for single speed, variable load operation. Use of these engines for variable speed, variable load mobile applications has not been demonstrated.

Glow Plug Operation

A glow plug, as described for use with methanol, can be used to assist in igniting the natural gas for combustion. This must be combined with a compression ratio that will allow for controllable ignition. The modifications to the diesel engine include additions for introduction of the natural gas, addition of a glow plug and appropriate design changes to allow for good operation. Some diesel engines currently utilize a glow plug to facilitate cold starting.

2.2 Case Studies

Several marine vessels and other vehicles with medium speed diesel engines have been converted to alternate fuel operation. This section describes several of these case studies.

2.2.1 Canadian Ferry

In 1985, the M.V. Klatawa, a 26 car ferry in Albion, Canada, was converted to operate on compressed natural gas. The ferry, originally built in 1972, is propelled by two Mariner L-295 drives, powered by two Caterpillar 3406B engines rated at 325 horsepower each. The Caterpillar engines were converted to dual-fuel operation utilizing carburetion by Mogas Fuel Systems Inc. in Vancouver, B.C. A combination of 88 percent natural gas and 12 percent diesel fuel pilot are normally used in operation of the vessel. The ferry is well-suited for natural gas operation due to the fact that it has a brief river crossing of only 15 minutes. This enables the number of storage tanks to be small, since frequent refueling is possible. Natural gas is stored on the ferry in two sets of four tank bundles at 3,000 psi. The storage volume on the ferry is 8,400 scf, or the equivalent of about 60 gallons of diesel fuel. The tanks need to be refilled at least twice each day. Refilling time is about 4 minutes as the service is equipped with a fast fill station.

2.2.2 Shrimp Boat

A new 22 meter shrimp boat in the Southeastern United States has been constructed with an integrated fuel system, a dual-fuel main engine and a dual-fuel generator. The objective of the project is to replace diesel fuel with natural gas in order to realize a 30 to 40 percent savings in fuel costs. The vessel is equipped with a Caterpillar 3406-B main engine and a Perkins 4.236 generator. Both of these are operating in the dual-fuel mode. The diesel injector rack movement of the engines is limited to 20 percent of normal range, thereby providing for a 80/20 gas/diesel ratio at full load. Low load operation is on 100 percent diesel fuel.

Due to the limited space onboard the vessel, the natural gas is stored in liquid form at about -260°F. This requires the use of two cryogenic tanks, urethane insulation, piping and

pressure controls and heat exchanger equipment. This type of storage provides the necessary energy density as 39 percent more volume would be needed than the equivalent amount of diesel fuel. Cryogenic storage also allows the fuel to be used for refrigerating for the cargo, providing for a further reduction in on-board diesel usage. The vessel carries about 4,500 gallons of LNG, or the equivalent of about 3,300 gallons of diesel fuel. This provides for a trip length of 14 - 21 days.

Liquid natural gas is loaded into the tanks from a natural gas liquification system on-shore. The tanks are insulated enough so that the fuel is kept cold for at least 20 days. Fuel from the cryogenic tanks must first be heated with heat exchangers before being introduced into the engine. This is done by utilizing the vessel need for refrigeration of shrimp cargo and by using engine coolant. Fuel is drawn from either the top or the bottom (vapor or liquid) of the tanks depending on tank pressure. The pressure inside the tanks can cause a rupture if the fuel is not used due to heat leaks. The tanks are equipped with relief valves and a burst disk to prevent tank rupture.

2.2.3 BN Locomotive

Burlington Northern Railroad (BN), in combination with the Northern States Power Company (NSPC), set out in 1984 to determine the feasibility of natural gas fuel for line haul railway locomotives. The motivation for the project came from the power company's desire to increase the potential market for natural gas, and the economic needs of the railway company.

The engine selected for use as a dual-fuel engine was the EMD 567-C. This engine has a stationary counterpart, the 567-CDF, with which NSPC has an extensive amount of experience operating in the dual-fuel mode. The 567-C is a locomotive engine which generates 1,750 bhp at 835 RPM. Its configuration is very similar to the 567-CDF except that the CDF is designed as a constant speed, variable load engine. The modifications to the 567-C involved adding the 567-CDF cylinder liners, heads, pistons, cam shafts and bearings, and applying a gas dual-fuel system to the engine. A governor linkage was specially designed by EMD for the dual-fueled system that was required for the variable speed and load requirements of the locomotive engine.

CNG tanks were installed on a trailer towed behind the locomotive. A flexible connection delivers the gas to the engine. Total storage volume is about 1,400 gallons of diesel equivalent.

The locomotive has completed Phase I and II of the project which involved static lab testing of the engine and inclusion of the modified locomotive in branch line service. A number of mechanical problem with the engine surfaced which BN felt were related to the use of the stationary, constant speed, variable load engine parts in a variable speed, variable load application. These problems included valve wicking and ring problems.

Mechanical problems were also noted due to the lower compression ratio. Results of the Phase II program have not been released to the public.

3.0 EMISSIONS FROM ALTERNATE FUELED ENGINES

Lower emissions would be the primary objective of converting marine vessels to alternate fuels. The actual benefits gained would depend on the type of alternate fuel technology that is utilized.

3.1 Methanol

The heat of vaporization of methanol is about 4.7 times greater than that of diesel fuel and the volume flow of methanol required to obtain the same energy input as diesel is more than twice that of diesel fuel. Together, these two factors will produce an order of magnitude greater temperature drop for methanol than diesel when the fuels are vaporized. For fuel injected engines, this occurs in the combustion chamber. This, combined with the greater amount of water produced during the combustion of methanol, provides a much greater cooling effect of methanol and thereby lower NO_x emissions.

Due to the low carbon/hydrogen ratio of methanol, combustion is relatively clean and soot-free. This reduces the level of particulate emissions. Methanol reduces particulate emissions by as much as 60 percent and smoke emissions are essentially eliminated.

Emissions of HC generally increase with the use of methanol. This is primarily due to the inability of the ignition systems to completely combust the fuel, resulting in high emissions of methanol out the exhaust pipe. Methanol increases emissions of aldehydes by an order of magnitude over those of a diesel engine. Emissions of CO generally increase with the use of methanol, due to the richer combustion characteristics required to generate the diesel equivalent power output.

Numerous emission tests on various diesel engines with different methanol technologies have been reported in the literature. The NO_x emissions of supply boat engines converted to methanol (assuming spark ignition) are likely to fall in the 2 - 5 g/hp-hr range, based on these tests, as well as our estimates of the NO_x emissions from the same technologies applied to supply boat engines.

<u>Methanol Technology</u>	<u>Range of Tests</u>	<u>NO_x Emissions in grams/bhp-hr</u> <u>Supply Boat*</u>
M100-Diesel Pilot	4 - 7	5 - 6
M80-Diesel Pilot	4 - 6	5 - 6
M100 with Ignition Enhancer	4 - 7	4 - 5
M80-Spark Ignition	4 - 7	4 - 5
M100-Glow Plug	1 - 6	1 - 3
M100-Spark Ignition	2 - 6	2 - 3

* Estimated NO_x emissions under typical cruise conditions.

Much of the wide variation in the engine emissions shown above can be attributed to the number of different engines and the effects of testing over different duty cycles. In addition, many of the data were conducted on test engines which have not yet been optimized for low emission performance. The estimated emission levels assume that the methanol technologies would be developed to produce low emissions on a supply boat duty cycle, optimized for cruise conditions where typically 80 percent or more of the emissions are generated.

It is possible to reduce HC, aldehydes and CO emissions with a catalyst. Studies have shown that the use of a standard production Pt-Pd catalyst reduces HC and CO, but converts a large percentage of the unburned methanol to formaldehyde, a known carcinogen. The use of a specially designed Pd-Ag or Pt-Rh catalysts was found to eliminate this problem.

3.2 Natural Gas

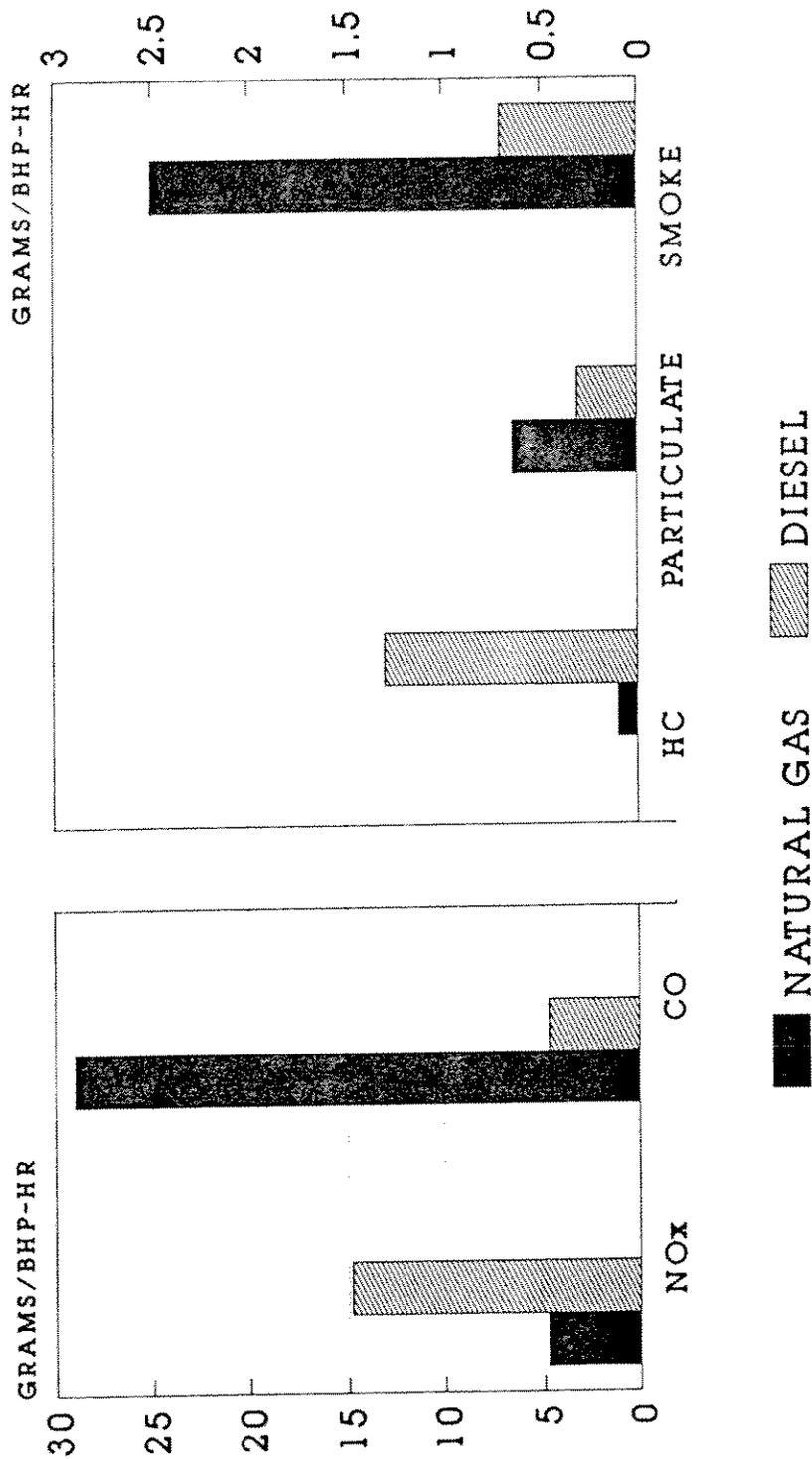
In contrast with diesel fuel, natural gas normally does not contain higher hydrocarbons and sulfur. This provides for a significant reduction in particulate emissions when natural gas is used. The ability of a natural gas engine to achieve low NO_x emissions is dependent upon utilizing either lean combustion techniques or an exhaust catalyst.

Conversions of highway diesel engines to natural gas operation utilizing carburetion techniques and diesel fuel #2 (DF2) pilot have produced 20 to 30 percent reductions in NO_x emissions with significant increases in HC and CO emissions; but use of the spark conversion technique with carburetion have produced better results for HC and CO. Thermal efficiency generally is lower at low loads and about the same near full load compared to a diesel engine.

Both Waukesha and Superior stationary natural gas engines (based on spark ignition) can achieve NO_x emissions below 2.0 grams/bhp-hr at full load with correspondingly low HC, CO and PM emissions. These engines achieve their low emissions through the use of a prechamber ignition system. This prechamber produces a "torch" of ignited gas into the combustion chamber. The system allows for operation at leaner mixtures which reduces NO_x emissions by reducing the peak combustion temperature. Retrofit systems for large lean-burn Cooper-Bessemer stationary engines also utilize this torch ignition technique. These stationary engines are normally operated at a single speed. Problems associated with use of an engine designed for single speed operation in a variable speed application are discussed in one of the case studies (Section 2.2.3).

Emission test results of an EMD 2-567B engine utilizing the high pressure injection system with a DF2 pilot for ignition are shown in Figure 3-1. This system generally showed an improvement in NO_x emissions; yet HC, CO and PM emissions have increased. It is

FIGURE 3-1
 EMISSIONS OF EMD 2-567B WITH
 NATURAL GAS FUELING



Note: EMISSIONS AT FULL LOAD
 (LOCOMOTIVE NOTCH 8)

believed that further optimization of the ignition system would provide for better HC, CO and PM emissions.

In summary, numerous emission tests on various engines employing different natural gas technologies have been reported in the literature. Our estimate of the NO_x emissions from applying these technologies to supply boat engines (or engine change out) are shown in the following table:

<u>Natural Gas Technology</u>	<u>Estimated NO_x Emissions in grams/bhp-hr</u>
Dual Fuel	5 - 7
Spark Ignition-Carburetor Optimized For Emissions	1 - 3
Late Cycle Direct Injection,	2 - 4
Diesel Pilot	3 - 6
High Pressure Direct Injection (Wartsila, Caterpillar)	6 - 10

Clearly, the spark ignited natural gas engine offers distinct NO_x advantages over the other technologies. Emissions of other pollutants can be minimized through engine optimization techniques.

4.0 SAFETY CONSIDERATIONS

Marine vessel design, construction, and operation incorporate numerous features to protect the safety of the vessel's crew. This section addresses those aspects of vessel safety which would be impacted from conversion to an alternate fuel.

4.1 Safety Hazards

The main safety issues associated with the use of CNG or LNG as an alternate fuel for supply boats are their flammability upon release from storage or the fuel system. For methanol, the hazards include flammability upon release; the potential for formation of flammable mixtures in fuel tank ullage; and toxicity. A condensed summary of important physical properties is given below:

	<u>CNG</u>	<u>LNG</u>	<u>Methanol</u>
Boiling Point (°F)	-259	-259	148
Vapor Density Relative to Air	0.54	1.46	1.16
Flammable Limits (vol. % in air)	5-15	5-15	6.7-36
Autoignition Temperature (°F)	1000	1000	725
Flash Point (°F)	-306	-306	52
TLV (ppm)	--	--	200
Storage Pressure (psig)	3000	<60	-0

Dispersion and Flammability

CNG releases will be all vapor and the high storage pressure will produce a high degree of mixing with air (due to jet effects) at relatively short distances from the point of release. CNG releases will also disperse readily in unconfined spaces because their vapor density is lower than air. LNG releases will form pools from which flammable vapor will evaporate. This vapor initially will be heavier than air, but will quickly attain positive buoyancy relative to air. Methanol spills will form vapors which are heavier than air. Methanol also has a much wider flammable range in air than natural gas and a lower ignition temperature. The net result of these factors is that methanol spills will form pools and disperse slowly. Given equal spill quantities, more methanol will generally be in the flammable range than LNG or CNG. The wide flammability limits of methanol also may present problems in fuel tanks where a flammable mixture may exist between 48-106°F.

All fuels are extremely hazardous if released in confined areas. In the open air CNG will disperse readily, while LNG and methanol vapors will initially stay close to ground level or collect in low points. It is important to consider these factors in locating fuel tanks and fuel lines. In fact CNG tanks might be located safely at an elevated location on the boat.

Refueling

Storage facilities for methanol could be similar to existing gasoline, including underground near atmospheric pressure tanks. Again the potential of having fuel vapors in the storage tank within the flammable range is of concern. CNG could readily be compressed from gas mains. The time to fill the CNG fuel tanks on a supply boat would provide more opportunity for a release such as a hose rupture or a situation where the boat was moved during the fueling and ruptured the fill line. The only current fueling system for LNG is from a cryogenic storage tank, although onside liquefaction from a gas main is possible. For LNG storage tanks, earthquake concerns would need to be addressed.

Other Safety Issues

Additional safety considerations, not described above, include:

- Difficulty in noticing LNG leaks: Odorants used for detecting leaks of natural gas are removed during LNG liquefaction, making a leak difficult to detect by odor.
- Incompatibility of methanol with some materials of construction, especially in the presence of water, could lead to failures and releases if not adequately addressed in the design.
- Boil-off of LNG which needs to be controlled with an activated carbon canister or other means. Uses for the saved boil-off could include combustion in the main engine or crew quarters' cooking and heating. Greenhouse concerns will likely eliminate the option of routine venting of methanol gas.
- Vulnerability to an external fire. The CNG tanks, being of very robust design, should withstand a fire, although the contents would be vented. Both methanol and LNG have the potential to BLEVE (Boiling Liquid Expanding Vapor Explosion).
- Methanol also is more toxic than natural gas.
- LNG poses a freeze burn hazard, particularly to station attendants during fuel tank filling. Equipment freeze-up is also a potential problem.

4.2 Safety Regulations and Standards

There are no safety regulations for using alternate fuels on vessels per se. There are regulations for marine vessel fuels, which are oriented toward conventional liquid fuels. Various regulations and standards have been adopted for onshore applications of alternate fuels. It is likely that the first uses of alternate fuels on vessels would incorporate standards from a variety of sources. If the first demonstrations are proven successful, vessel safety regulations might be adopted by various agencies.

Federal regulations which might apply to some aspects of alternate fuels include:

- 29 CFR General Industrial Safety and Health Standards (Refueling),
- 33 CFR Navigation and Navigable Waters,
- 46 CFR Shipping, and
- 49 CFR Transportation (storage, vaporization, liquefaction and cargo tanks).

In addition, certain state regulations might also apply. Guidelines or recommended practices have also been developed by government agencies. For example, the California Energy Commission has published guidelines for the selection of methanol compatible materials.

National industrial and safety organizations have established various standards which should apply to certain aspects of the alternate fuel system, including:

- ASME Boiler and Pressure Vessel Codes for CNG and LNG tanks,
- DOT natural gas cylinder specifications,
- NFPA 52 for CNG fueling and automotive systems, and
- NFPA 59A for LNG storage and transfer facilities.

Further guidelines and standards for alternate fuels can be expected as these fuels penetrate the automotive market.

Other institutions which will concern themselves with the safety of alternate fuels are classification agencies, such as the American Bureau of Shipping. These agencies independently evaluate marine vessels for the purpose of insuring them. As a result, they have published guidelines for vessel design. It would be desirable to have a classification agency participate in the development of alternate fuels on a supply boat so that conventional insurance could be available.

5.0 VESSEL DESIGN AND OPERATIONS

A wide variety of supply boats have been used for California oil and gas development projects. These boats have ranged in length from 140 to 220 feet and in power rating from 1400 to 8000 hp. Most of the supply boats which have been used for California offshore projects fall into one of the two following classes:

160 to 180 foot coastal supply boats with 2000 to 2500 hp rated engine capacity. These vessels typically are rated at a deck cargo carrying capacity of about 500 tons and have approximately 50,000 gallons diesel storage capacity.

180 to 200 foot ocean going supply boats with 4000 to 5500 hp rated engine capacity. Many vessels in this class are classified as Anchor Handling Tug and Supply Vessels. These vessels typically are rated at a deck cargo carrying capacity of about 600 tons and have approximately 75,000 gallons diesel storage capacity.

For existing California offshore projects, 2500 hp supply boats are appropriate for servicing projects near the ports of Long Beach and Los Angeles and for facilities located in the Santa Barbara Channel. The larger vessels are more appropriate for offshore facilities located north of Point Conception.

Alternate fuels, either methanol or natural gas, would be more readily installed on a 2500 hp class supply boat than on a larger class. These vessels typically have shorter runs than their larger counterparts and also consume less fuel per unit distance travelled. As a result, the alternate fuel storage requirements for the smaller class of supply boats would be much less than for the larger class. It is thus assumed that alternate fuels, if used on supply boats, would first be demonstrated and developed for the 2500 hp class. The analysis presented in this section are based on analyzing this smaller class of supply boats.

There are many aspects of boat design and operation which would be affected by a conversion to an alternate fuel. This section highlights some of the most important of these considerations, including:

- Engine Power,
- Emergency Refueling,
- Vessel Mobility,
- Vessel Capacity and Cruising Range, and
- Other Safety-Related Design Constraints.

While every effort has been made to address the most critical of issues to vessel operation and the industry, there are undoubtedly additional considerations which should be accounted for prior to converting a vessel to an alternate fuel.

5.1 Engine Arrangements

An arrangement of main engines, reduction gears, and auxiliary engine generator sets which is typical of supply boats servicing California platforms is shown in Figure 5-1. This figure displays two main engines, each connected to its own reduction gear and propeller shaft, and two independent engine generator sets.

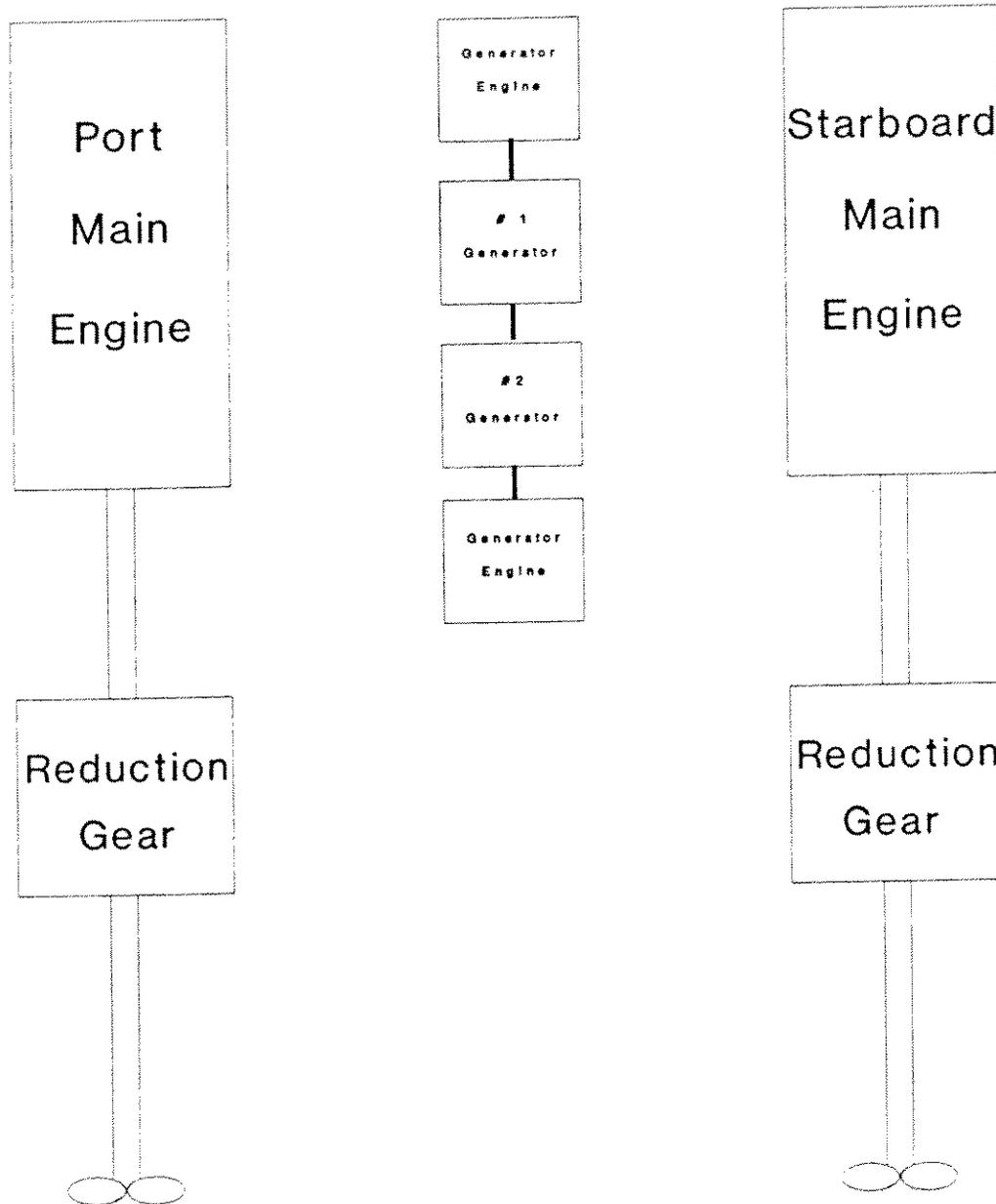
The engine arrangements for a vessel utilizing an alternate fuel will probably depend on the maturity of the technology in marine applications. During the early stages of deployment of alternate fuels for boats, prudence would dictate that a boat should be able to run on a conventionally available fuel (i.e., diesel). Diesel fuel would be used if the alternate fuel was not available, if the alternate fuel system failed or if the vessel entered service in a region where the alternate fuel is not available. The configuration which provides diesel and alternate fuel firing is two dual fuel main engines which are capable of operating on either the alternate fuel or straight diesel fuel.

After alternate fuel technology for marine vessels becomes mature and proven reliable, dedicated vessels could be built and operated. These vessels would then be configured in one of two ways:

- Conventional two engine configuration (shown in Figure 5-1). Both engines would be dedicated to the use of the alternate fuel. The engine's design would be optimized for emissions.
- Three engine electric configuration (shown in Figure 5-2). This configuration would allow for the use of alternate fuel technologies, such as clean burn natural gas, which are optimized for steady speed, variable load applications.

The engine configurations that would be used for alternate fuels would add considerable weight to a vessel. For the dual fuel configuration, two fuel systems would be installed, adding weight to the vessel. The three engine generator configuration would add even more weight. If an existing vessel was converted to alternate fuel use, then the cargo carrying capacity of the vessel would be reduced. On the other hand, if it was deemed desirable that the cargo capacity be maintained constant, then a new vessel would have to be designed, incorporating a slightly larger displacement and engine rating.

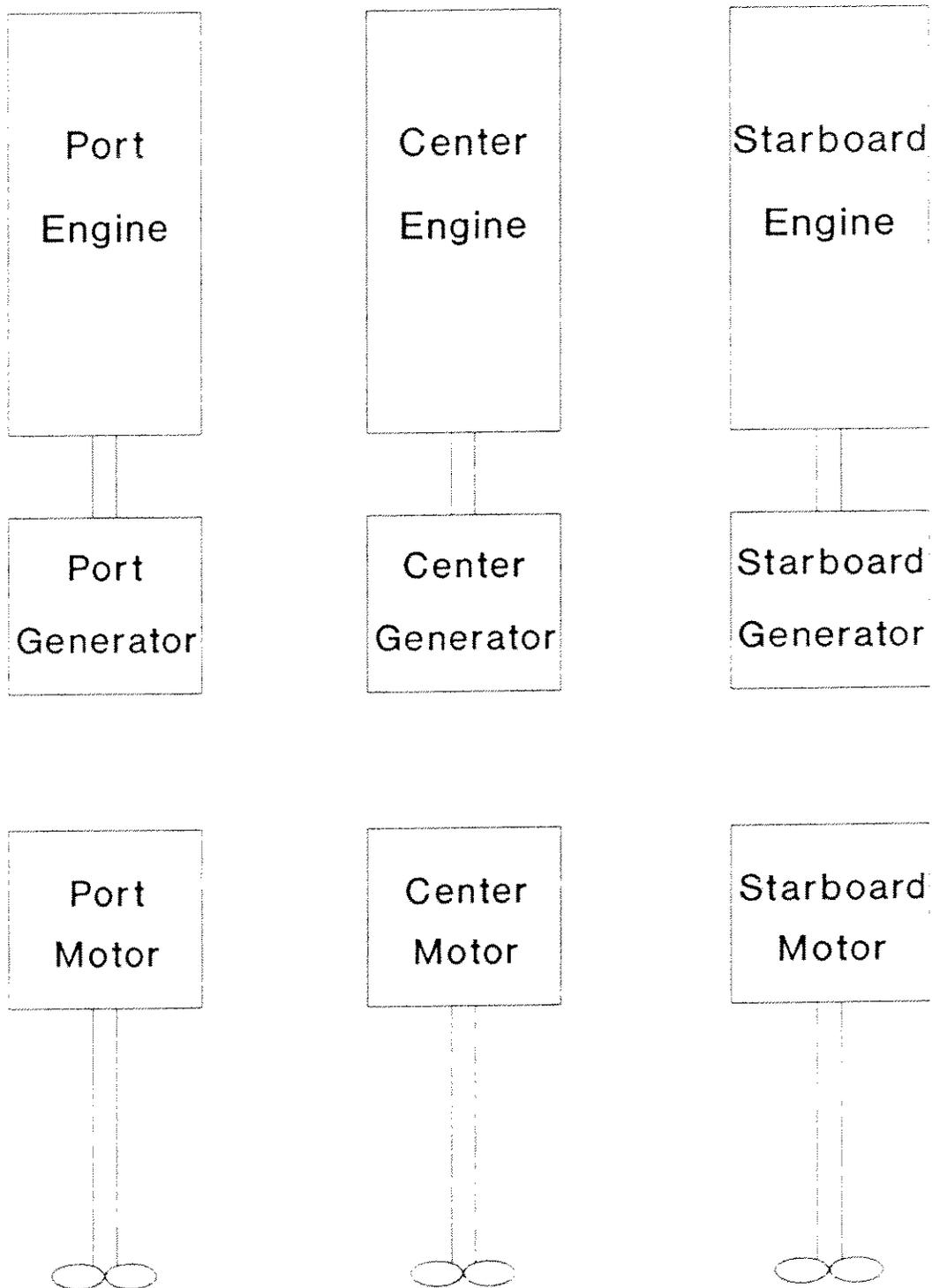
FIGURE 5-1
CONVENTIONAL SUPPLY BOAT
ENGINE CONFIGURATION



Note: This configuration is applicable to some alternative fuel configurations:

- dual fuel main engines
- dedicated alternative fuel vessel

FIGURE 5-2
ELECTRIC SUPPLY BOAT CONFIGURATION



5.2 Fuel Storage and Delivery

The storage and delivery of an alternate fuel on a marine vessel poses a number of challenges. Both methanol and natural gas have poorer energy storage densities than diesel fuel. Natural gas, if compressed, requires heavy high pressure storage containers, and if liquified, requires a significant amount of equipment to maintain equilibrium in the system. Methanol's energy storage density (half of that of diesel fuel on a per unit volume) poses a storage volume difficulty and its corrosive nature dictates highly resistant metals and materials. This section presents an overview of many of the design issues related to the fuel storage and delivery system for these two fuels.

Compressed Natural Gas

Compressed natural gas, at a pressure of 3000 psi, has a equivalent energy storage density about four times less than diesel fuel. This storage density ratio is only for the actual fuel. If the storage cylinders and their corresponding void spaces are included, CNG requires about six times as much space as the equivalent amount of diesel fuel.

In addition, CNG requires high pressure containers of a small diameter and high weight relative to a diesel fuel tank. In order to allow for a high pressure, thick tank walls are required. At pressures above 3000 psi, the benefits due to higher gas density are offset by the loss in volume due to thicker walls.

The high pressure containers are very heavy. Using ASME natural gas storage vessels rated at 4000 psig maximum, the weight associated with storing CNG is six times the weight for storage of the equivalent amount of diesel fuel. For example, a diesel tank holding 6000 gallons would weigh about 25 tons, whereas the weight to store the equivalent amount of CNG would be about 137 tons. This CNG storage could represent as much as 50 percent of the cargo carrying capacity of the supply boat.

Liquified Natural Gas

Due to the weight and size limitations of storing relatively large volumes of CNG onboard a vessel, the storage of the natural gas in a liquid form might be considered. Natural gas becomes a liquid at temperatures below about -250°F under atmospheric pressure. The liquid is stored in cryogenic tanks that are insulated to prevent heat leaks and allow for storage of the liquified gas for up to about 20 days without additional liquefaction procedures. The gas must be used in this time as the pressure in the tanks increases as the liquid slowly warms up.

The volumetric energy (BTU/ft³) of natural gas is less than diesel. About 39 percent additional space is required to achieve the equivalent amount of diesel fuel. Additional storage space would be required for the insulation and the cryogenic tanks. The weight of

LNG storage would not be significantly increased over the weight of diesel storage as the specific gravity of LNG is half that of diesel fuel.

A control system to monitor the pressure in the tank and control the withdrawal of either gas or liquid is required. If the pressure is too high, the gas at the top of the tank is used by the engine. If the pressure is not too high, liquid is drawn from the bottom. The liquid and gas must also be heated, or vaporized, before being used in the engine. This can be done with the engine coolant. In the shrimp boat case study discussed above, the cargo was also cooled by this process.

Methanol

The volumetric energy content of methanol is less than diesel by about 56 percent. Therefore, about 127 percent more space is required to achieve the equivalent amount of diesel fuel. Since the specific gravity of methanol is only slightly lower than diesel fuel, weight requirements for the storage of methanol would also increase by at least a factor of two.

Due to the highly corrosive nature of methanol, special attention should be given to the materials of construction of tanks and fuel delivery lines.

5.3 Impacts on Vessel Ratings and Utility

The two most significant impacts on vessel capabilities and operations that are accruable to the use of alternate fuels are impacts on the vessel's cargo carrying capacity and its cruising range. The following table shows the weight and volume impact of the three different alternate fuel configurations:

	Weight Ratio <u>to Diesel</u>	Volume Ratio <u>to Diesel</u>
CNG **	6	6
LNG	-1.0	2*
Methanol	2.1	2.3

* Additional volume due to insulation and controls indicated.

** Conventional steel tanks.

All three of these design configurations assume that the present boat volume for fuel storage remains unchanged. As a result, all three of these configurations portray a lower cruising range. Alternately, a vessel could be designed with an identical cruising range, although this would be at the expense of cargo carrying capacity.

5.4 Refueling Operations

Refueling of an alternate fueled boat requires the changing of the fueling facility from diesel. Modifications range from changing of tanks and delivery lines to installation of multimillion dollar pumping stations. The refueling station requirements for CNG, LNG and methanol are discussed below.

Compressed Natural Gas

The storage of natural gas on the vessel at 3000 psig requires a facility capable of compressing pipeline gas to 3000 psig. A fuel storage capacity equivalent to 6000 gallons of diesel fuel would require 850,000 scf of natural gas.

The compressor station would be composed of multiple compressors and storage of enough gas to allow for reasonable fill times and efficient use of the compressor power. The system would be a hybrid design, in which both the gas storage and the compressors are needed during refueling. This hybrid system optimizes both the amount of onshore storage requirements and the compressor horsepower and compressor down time.

The compressors deliver the gas to the storage cylinders, which are then able to discharge the gas quickly to the boats. A refueling station capable of refueling the vessel in two hours would have three 500 hp compressors and about 600,000 scf of gas storage. The compressors would spend about five hours recharging the cylinders.

Connections to the vessels would be made with flexible connections similar to those used to connect the fuel car to the locomotive in the Burlington Northern case study described in Section 2. The refueling station would have to be located on or near the docking location to minimize the pipeline connections.

The control system includes flow and temperature control to prevent overpressure of the tanks onboard the vessel. Emergency provisions include burst disks and automatic shutdown valves which close automatically if a preset flow rate is exceeded.

Liquified Natural Gas

A natural gas liquefaction facility is required if LNG is the alternate fuel of choice. The configuration of a liquefaction facility is dependent upon the available gas pressure and the gas composition. CO₂, water, odors, and other elements which solidify at LNG temperatures, must be removed using molecular sieves. Liquefaction techniques depend on inlet pressure and may include Joules Thompson (expansion) cooling; mechanical refrigeration using cascade or mixed refrigerants; or stirling cycles. Pressure drop liquefaction is the most economically attractive technique if a gas pressure source above 800 psia is available and the low pressure gas can be distributed to other requirements.

Self contained skid liquifiers which separate their own gas pressure for this cycle are available but they use up to 28% of the fuel for liquefaction.

The advantage of LNG is that the liquefaction facility can be located apart from the docking location and the liquified gas can be transported to the dock via cryogenic container trucks. This enables the liquefaction facility to be located near a natural gas main line where high gas pressures are already available. This transportation scheme has been safely demonstrated for many years to service gas system satellite peak storing storage plants. In some instances, location of a liquefaction plant at a main trunk pressure letdown station can allow liquefaction of a small fraction of the gas stream with very small energy inputs.

Refueling of the cryogenic tanks onboard the vessel will use flexible vacuum jacketed connectors similar to the type used in the shrimp boat case study discussed above.

Methanol

The use of methanol on a vessel would require the replacement of the standard diesel refueling facility due to the requirements for materials more resistant to corrosion. These materials include methanol resistant plastics such as polyethylene and polypropylene or stainless steels. The configuration of tanks and piping would be similar to a standard diesel refueling station.

6.0 FUEL SUPPLY AND INFRASTRUCTURE

Methanol and compressed natural gas presently are available as a transportation fuel only for pilot demonstration programs. Fuel supply, availability, reliability and price would be important considerations for utilizing alternate fuels for supply boats. These factors would be affected by the breadth of penetration of these fuels into transportation and other markets. Fuel supply and infrastructure are analyzed for both methanol and natural gas in the following sections.

6.1 Methanol Fuel

Methanol fuel is presently used in California for several demonstration programs, such as Golden Gate Transit in the Bay Area and the Rapid Transit District in the Los Angeles area. Studies by the California Energy Commission (CEC) show a strong dependence of methanol use on its price. The price of methanol for use on a supply boat would depend on its price for on-road transportation uses. Other factors which could influence methanol supply for offshore work boats include source and reliability of supply, blending techniques and facilities, and fuel storage and refueling capabilities at the port(s).

6.1.1 Methanol Transportation Fuel Price

Methanol fuel for California's present demonstration programs is shipped via rail tanker car from Canada. The approximate price of methanol fuel for the pilot programs is given below.

	cents per gallon <u>methanol</u>	cents per gallon diesel <u>equivalent</u>
Methanol, FOB Canada	35	75
Rail Freight	<u>17</u>	<u>37</u>
Subtotal (FOB LA)	52	112
Distribution	2	4
Fueling Station	4	9
Road Taxes	<u>6</u>	<u>13</u>
Total Price	64	138

The delivered fuel price estimates in the right hand column can be compared to the current price of DF2 to industrial users (about 50 - 70 ¢ per gallon). Considerable documentation exists which suggests that the price of methanol fuel in the future would be different than that of today. These various forecasts, which span quite a broad range, are all predicated on the assumption that the demand for methanol fuel in the transportation sector grows to

a point where economies of scale can be enjoyed. If methanol demand does not grow substantially, then the costs can be expected to be similar to those above or, if different, somewhat higher, owing to the present global oversupply of methanol and the deep price discounting of recent years.

World-wide methanol supply is approximately 7 billion gallons per year. Demand is approximately 5 billion gallons, most of which is for chemical feedstock. Feedstock methanol demand is not expected to increase at a rate larger than average economic growth; methanol demand for blending and for production of MTBE is expected to grow substantially over the next few years. As a result, few capacity expansions are planned at the present time. A forecast of global methanol supply and demand prepared by the CEC is shown in Figure 6-1.

The future cost of methanol fuel will depend primarily on two factors:

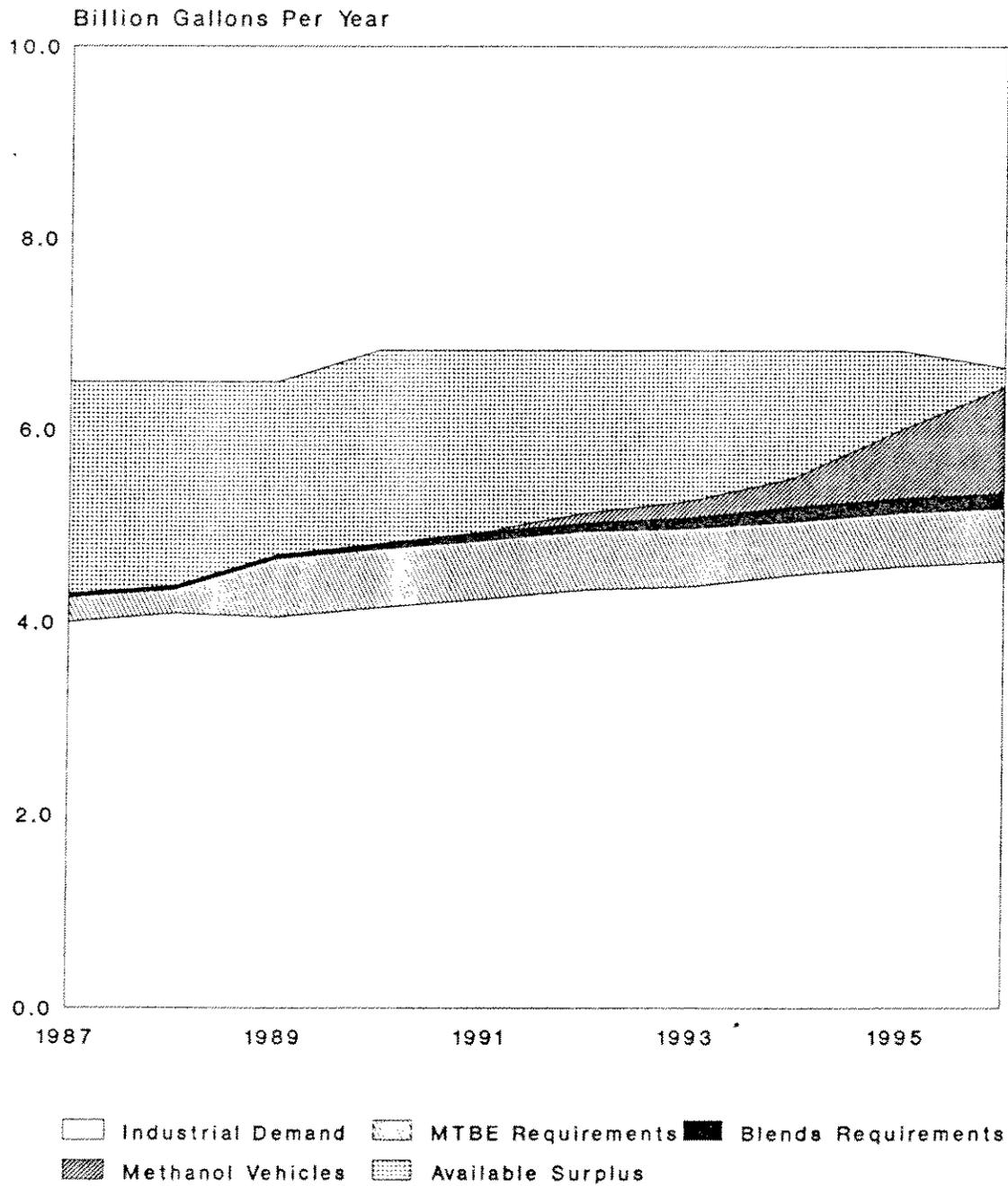
Transaction price of methanol at its source, and
Transportation to California

Additional costs will depend on the particular end-use. For supply boats, the additional costs would include local transportation and vessel refueling facility charges. Supply boat methanol usage would not be subject to some of the marketing and tax charges that would be incurred for highway use of methanol fuel.

Many forecasts of potential California methanol fuel demand suggests that the most economical methanol fuel would come from foreign sources. Although the transaction price for importing methanol would depend on market conditions, the CEC has prepared estimates of the variable costs for methanol from different potential sources. Inherent to these forecasts, however, are many assumptions related to internal valuation of natural gas (the feedstock for methanol production) and foreign currency valuation.

The CEC has estimated the variable costs associated with methanol production from a variety of countries. These estimates range from 13 cents per gallon for Argentina to 33 cents per gallon for the U.S. Capital charges are estimated to be 17 cents per gallon in the long term. Transportation costs are estimated to range from 2 to 5 cents per gallon for North American sources, 5 to 7 cents per gallon for South American Sources and 8 to 11 cents per gallon for Middle East and Asian sources. All of the transportation costs were estimated assuming a relatively large penetration of methanol into the transportation fuel market. The overall CEC forecast/target of 42 cents per gallon, delivered to Los Angeles, is based upon capital charges of 17 cents, variable costs of 16 cents and transportation costs of 9 cents, on a per gallon basis. This corresponds to 90 cents per gallon DF2 equivalent, which is roughly 50% above the current price of DF2 to the marine industry.

FIGURE 6-1 WORLD METHANOL SUPPLY AND DEMAND



Source: California Energy Commission

Other estimated costs for methanol fuel vary substantially from the CEC's long term landed cost target of 42 cents per gallon. In the shorter term the CEC predicts even lower methanol costs, resulting from short term price reductions due to the present global methanol oversupply. Other CEC forecasts range from 26 to 58 cents per gallon. Other price forecasts, such as that quoted by the American Gas Association (AGA) claim that the long term landed price of methanol fuel will be approximately 70 cents per gallon.

Various methanol price scenarios and their diesel fuel equivalents are shown below.

	Methanol Price in \$/gal	Equivalent Price for Diesel Fuel in \$/gal
Present California System	0.52	1.12
CEC Long Term Target	0.42	0.90
CEC Long Term Minimum	0.26	0.56
CEC Long Term Maximum	0.58	1.24
AGA Long Term Forecast	0.70	1.51

In only one of the five forecasts, the CEC long term minimum, would methanol fuel be price competitive with diesel fuel, which has a current wholesale price of 55 to 65 cents per gallon. Other forecasts would imply a fuel price penalty for methanol fuel which could be as great as 150 percent.

6.1.2 Additional Methanol Supply Factors

Although the uncertainty of the price of methanol fuel is the largest supply issue faced by the alternate fuel, there are other supply issues of relevance to its potential use on supply boats. Issues which are described in this section include reliability of supply and fueling infrastructure at a port facility.

There are many factors which suggest that, at least in the near term, the reliability of methanol should be relatively high. The present global methanol capacity glut would suggest that methanol availability and reliability from its source will be high over the next several years. In the longer term, methanol can be produced from a variety of feedstocks, not only natural gas, but other fuel sources such as coal and wood. However, some of these process routes, such as methanol from coal, are not economical at present day energy prices.

The distribution infrastructure for methanol fuel in California is presently embryonic. Infrastructure which would be required for using methanol on supply boats would include methanol storage at California point of delivery, local transportation to the port facility and

storage and refueling capabilities at the port. Due to the corrosive properties of methanol, new facilities would have to be constructed at the port -- existing fuel storage facilities cannot be readily converted to methanol fuel. Such facilities would include methanol storage, blending and gasoline storage (if required), and refueling. The vessel refueling system would need to be designed to new, stringent specifications, resulting from methanol's toxicity to humans, its miscibility in water and its corrosiveness.

6.2 Natural Gas Fuel

Supply issues for natural gas fuel are quite different from those of methanol. Natural gas is widely available throughout California, supported by an extensive transmission and distribution network. The reliability of future natural gas supplies in California, however, has been questioned by some parties.

6.2.1 Natural Gas Fuel Price

The price of natural gas fuel for a supply boat application would be dictated by two factors:

- Delivered price of gas, which would be similar to that for small industrial users; and
- Cost of purchasing and operating a natural gas compressor fueling station at the port.

Both of these factors are described in this section.

In the short term, natural gas is competing with methanol and other alternate fuels for a new market in the transportation sector. As a result, favorable terms for CNG delivered to a vessel might be available. In the longer term, whether or not natural gas becomes a significant transportation fuel, its price delivered to the compressor station will approximate that paid by smaller industrial users. This price is presently around \$4.50 per million BTU (or 63 cents per gallon diesel equivalent). Due to the deregulation of natural gas pricing, industrial prices for gas can be expected to follow the prices of competing petroleum products.

The cost for owning and operating a natural gas compressor station at the port facility would depend strongly on the station's design. The economics of operating a CNG compression/fill facility at a port, can be estimated as follows. Typical retail refueling stations consist of compression trains plus a high-pressure, cascaded storage system. A facility for refueling vessels would require a very large CNG cascaded storage capacity and a high flow rate compressor. The cost of operating such a system would depend on the number of boats utilizing the station. Table 6.1 outlines the operating costs of a CNG and a LNG refueling facility. As the number of vessels, or the frequency of refueling increases,

TABLE 6.1
OPERATING COSTS OF CNG AND LNG REFUELING STATIONS

CNG

	1	2	4	8
NUMBER OF BOATS				
CAPITAL COST	\$2,000,000	\$2,000,000	\$2,000,000	\$2,000,000
TOTAL COMPRESSOR HP	1,500	1,500	1,500	1,500
COST PER KWHR, \$	0.06	0.06	0.06	0.06
MAINTENANCE COST PERCENT	3	3	3	3
CAPITAL CHARGES AT 17%	\$340,000	\$340,000	\$340,000	\$340,000
COMPRESSION ENERGY COST	\$34,295	\$68,589	\$137,179	\$274,358
MAINTENANCE	\$60,000	\$60,000	\$60,000	\$60,000
TOTAL ANNUAL COST	\$434,295	\$468,589	\$537,179	\$674,358
COST / EQUIVALENT DIESEL GAL	\$1.39	\$0.75	\$0.43	\$0.27

LNG

	1	2	4	8
NUMBER OF BOATS				
CAPITAL COST	\$2,000,000	\$2,000,000	\$2,000,000	\$2,000,000
TOTAL COMPRESSOR HP	1,500	1,500	1,500	1,500
COST PER KWHR, \$	0.06	0.06	0.06	0.06
MAINTENANCE COST PERCENT	5	5	5	5
CAPITAL CHARGES AT 17%	\$340,000	\$340,000	\$340,000	\$340,000
COMPRESSION ENERGY COST	\$34,295	\$68,589	\$137,179	\$274,358
MAINTENANCE	\$100,000	\$100,000	\$100,000	\$100,000
TOTAL ANNUAL COST	\$474,295	\$508,589	\$577,179	\$714,358
COST / EQUIVALENT DIESEL GAL	\$1.52	\$0.82	\$0.46	\$0.29

the facilities become more utilized and the cost per equivalent diesel gallon decreases. Estimated operating costs for CNG (over and above the natural gas price) range from \$0.27 to \$1.39 per equivalent diesel gallon for one to eight vessels, or facility visits, every five days; and \$0.29 to \$1.52 for one to eight vessels for LNG. LNG is somewhat higher due to the expected higher maintenance requirements of a cryogenic facility. Costs for operating a skid mounted pressure drop liquefaction unit, as described in Section 5.4, could be considerably less. Safety issues and dock availability suggest that the overall utilization of a refueling system would be low. For this reason, the costs presented here are somewhat higher than those for other applications of CNG and LNG.

For comparison, retail CNG compression facilities for light duty highway vehicles range in cost from \$50,000 for small, slow-fill systems to over \$500,000 for large, fast-fill facilities. Fully-loaded operating expenses for such CNG compression and refueling stations, including amortization of capital expenditure, are approximately \$2.27 per million BTU (or 32 cents per gallon diesel equivalent), according to the AGA.

Thus, at conventional natural gas supply prices, the price of compressed natural gas fuel can be expected to be greater than diesel fuel price by 20 to 60 percent. However, in this new era of gas de-regulation, other options might be available for a natural gas supply boat, considering that most of the projects which they support also produce natural gas. The potential of unbundling, a current thrust within the gas industry, in which services are disaggregated, implies that an OCS operator might be able to purchase service from a gas utility to transfer gas from the plant site to the port, paying only for this transportation service. Considering that the wellhead value for this gas is approximately \$2.50 per million BTU (\$0.43 per gallon equivalent), this scheme might be able to deliver gas to the port for about \$3.00 per million BTU, resulting in a vessel fuel charge quite favorable to that for diesel.

6.2.2 Additional Natural Gas Supply Issues

Reliability of the natural gas source as well as that of the compression and fueling station are also important issues. Both of these areas are discussed in this section.

Reliability of Gas Supply

The reliability of gas purchased from a gas utility would depend on the utility's supply network and the type of gas service that is chosen. Interruptible and priority gas services are available from the utility, priority service demanding a price premium.

Several sources have suggested that curtailment of some gas services might occur more frequently in California over the next several years, as the utilization of supply networks approaches their capacity. California presently produces about 30 percent of the state's gas demand; by the year 2007, California production is expected to diminish to about

16 percent of demand. As a result, new supply routes and pipelines will be required to ensure adequate gas supply. The possibility of service curtailment and temporary shortages might exist until sufficient new capacity exists.

Natural gas supplied by the oil and gas project itself, with backup and transportation services provided by the gas utility, might provide the most reliable gas supply for a marine vessel. The economics of this option might also be quite attractive. Regardless of which supply route is chosen, the impacts of a short term curtailment could be avoided through sufficient CNG storage capacity at the port facility.

7.0 INSTITUTIONAL CONSIDERATIONS

This section describes institutional considerations which are beyond the scope of the safety considerations described in Section 4.0. The two broad areas of other institutional concerns that are discussed here are training and financing.

7.1 Training

The number and types of individual employed on a boat, as well as their training and qualifications, are generally well-defined by unions and regulatory agencies. In utilizing alternate fuels on a supply boat, many or all members of a vessel's crew would need to be trained in a variety of technical areas related to the use and handling of a given fuel.

Overall, training requirements would include the following subjects:

Normal Operations

- Refueling
- Engine Operation and Maintenance
- Fuel handling and Precautions

Fuel System Problems

- General Troubleshooting
- Leak/Rupture Identification
- Leak/Rupture Repair
- Emergency Procedures

Fuel Hazards

- Flammability
- Toxicity

Not all of these subjects would be required by each category of personnel.

Training considerations not only entail the subjects or curriculum, but also include trainer certification, course standardization, testing/registration, and refresher courses. All of these aspects of training would need to be resolved to utilize alternate fuels on supply boats.

7.2 Financing

Financing the full cost of utilizing alternate fuels on supply boats poses a significant barrier to their adoption. Industry convention is that all investments in supply boats are borne by the vessel owners and operators. Oil companies which operate offshore projects then charter the vessels on either a spot (short term) or contract (typically one to two year)

basis. The charter arrangements cover the vessel as well as its maintenance and the crew; oil companies generally provide the fuel and lubricants directly.

Any vessel which is converted to alternate fuels would be limited to operating in the California area, where refueling infrastructure would be available. Limiting a vessel to serving one particular market is contrary to industry practice on the parts of both the vessel owners and the charterers. These factors suggest that an alternate fuel supply boat might need to be chartered under a long term agreement, for a time of approximately 5 to 10 years. A charter agreement of this duration could also include or establish the basis for a mechanism to finance the new vessel construction or vessel conversion.

Under a long term chartering arrangement, several financing mechanisms might be available:

Oil Company Financing - the project operating oil company, which has primary responsibility for air pollution control, could provide capital for constructing the alternate fuel vessel with the vessel operator providing crew and maintenance only on a fee for service basis.

Vessel Owner Financing - with a long term charter contract in hand, a vessel owner could obtain financing through its conventional means.

Third Party Financing - a long term charter contract could provide security for a leasing arrangement, based upon third party investment.

Construction of an alternate fueled supply boat on speculation might be another option. The use of such a vessel, however, would need to be mandated, since its operating costs would be much greater than a diesel fueled boat. But if an oil company were mandated to utilize alternate fuels on a supply boat, it is likely that one of the three options above would be utilized to provide assurance of vessel availability. Unless the level of California OCS industry activity rebounds dramatically, it thus appears that construction on speculation is not a likely option for alternate fuel supply boats.

7.3 Insurance

Conventional liability insurance would probably not be available for a vessel on which alternate fuels are being developed. Classification agencies might not be willing to approve a vessel prior to extensive at sea testing. During this period, two options might then be considered: limited liability insurance or self-insurance. Whichever option is chosen, a third party would probably need to underwrite the balance of the liability protection. The most likely candidate would be the oil company which is sponsoring the development of the alternate fuel supply boat.

REFERENCES

- 1) "A Fuel for the Future: Compressed Natural Gas." Garry Mauro. Presented at the Air & Waste Management Association's 82nd Annual Meeting & Exhibition at Anaheim, California during June 25-30, 1989. Publication #89-63A.2.
- 2) "A Neat Methanol Direct Injection Combustion System for Heavy-Duty Applications." Craig A. Kroeger. Presented at the International Off-Highway and Powerplant Congress and Exposition in Milwaukee, Wisconsin during September 8-11, 1986. SAE Publication #861169.
- 3) "Aldehyde and Unburned Fuel Emissions from Methanol-Fueled Heavy-Duty Diesel Engines." Frank Lipari and Donald Keski-Hynnala. Presented at the International Congress and Exposition in Detroit, Michigan during February 24-28, 1986. SAE Publication #860307.
- 4) An Economic and Efficiency Comparison of Alternative Vehicle Fuels: 1987 Update. Published by Energy Analysis, American Gas Association Planning and Analysis Group. September 22, 1987.
- 5) "An Even Playing Field for Alternative Fuels: What Economics Tells Us." Jane V. Hall. Presented at the Air & Waste Management Association's 82nd Annual Meeting & Exhibition at Anaheim, California during June 25-30, 1989. Publication #89-63B.4.
- 6) An Investigation of High Pressure/Late Cycle Injection of CNG As a Fuel For Rail Applications. J.F. Wakenell, G.G. O'Neal. Q.A. Baker and C.M. Urban. Southwest Research Institute for the Oak Ridge National Laboratory of the U.S. Department of Energy, Office of Transportation Systems, Alternative Fuels Utilization Program. Publication #ORNL/Sub--8522032/1, DE88 009000. April, 1988.
- 7) "Availability of Alternative Fuels, The Chicken and Egg Problem." K. Koyama, K.D. Smith, L. Ghaffari, California Energy Commission and C. Moyer, Acurex Corporation. Presented at the Air Pollution Control Association's International Workshop Series On Ozone in San Francisco, California on November 18, 1987.
- 8) "Catalyst Evaluation on a Detroit Diesel Allison 6V-92TA Methanol-Fueled Engine." R.W. McCabe, P.J. Mitchell, F. Lipari, W.F. Scruggs and R.C. Warburton. Presented at the International Fuels and Lubricants Meeting and Exposition in Toronto, Ontario, Canada during November 2-5, 1987. SAE Publication #872138.

- 9) "Catalysts for Methanol Vehicles." Gregory K. Piotrowski and J. Dillard Murrell of the U.S. Environmental Protection Agency. Presented at the International Fuels and Lubricants Meeting and Exposition in Toronto, Ontario, Canada during November 2-5, 1987. SAE Publication #872052.
- 10) "Comparative Study of Heavy-Duty Engine Operation with Diesel Fuel and Ignition-Improved Methanol" H.O. Hardenberg. Presented at the International Fuels and Lubricants Meeting and Exposition in Toronto, Ontario, Canada during November 2-5, 1987. SAE Publication #872093.
- 11) Crew and Supply Boat NO_x Control Development Program. The Santa Barbara County Air Pollution Control District with technical assistance from Arthur D. Little, Inc. and funding provided by Chevron U.S.A. June 1987.
- 12) Direct Gas Injection with Glow Plug Ignition. B.G. Richards. Annual Report by Caterpillar Inc. sponsored by the Gas Research Institute (GRI), Chicago, Illinois. August, 1988. GRI Publication #GRI88/0271.
- 13) "Distribution Systems and Costs for a Regional Fuel Methanol Market." John Glen Holmes, Energy and Environmental Analysis, Inc. Presented at the International Fuels and Lubricants Meeting and Exposition in Portland, Oregon during October 10-13, 1988. SAE Publication #861573.
- 14) Emission Characterization of an Alcohol/Diesel-Pilot Fueled Compression Ignition Engine and its Heavy-Duty Diesel Counterpart. Terry L. Ullman and Charles T. Hare. Final Report for the U.S. Environmental Protection Agency Mobile Source Air Pollution Control. EPA Report #460/3-81-023. August, 1981.
- 15) "Emissions and Fuel Economy of a Prechamber Diesel Engine with Natural Gas Dual Fuelling." Xianhua Ding and Phillip G. Hill. Presented at the International Congress and Exposition in Detroit, Michigan during February 24-28, 1986. SAE Publication #880069.
- 16) "Emissions and Fuel Economy Test Results for Methanol and Diesel Fueled Buses." Gilles A. Eberhard, Matthew Ansari and S. Kent Hoekman of the Chevron Research Company in Richmond, California. Presented at the Air and Waste Management Association's 82nd Annual Meeting and Exhibition at Anaheim, California during June 25-30, 1989. Publication #89-9.4.
- 17) Environmental Benefits of CNG-Fueled Vehicles. Topical Report. November 1986 - May 1987 by the Gas Research Institute of Chicago, Illinois. Reproduced by the U.S. Department of Commerce. Publication #GRI-87/0265.

- 18) Evaluation Report - California's Methanol Program. Prepared by the Acurex Corporation of Mountain View, California for the California Energy Commission, Sacramento, California. November, 1986. Consultant Report #P500-86-012.
- 19) Exhaust Emission Measurements of a Dual Fuel Caterpillar 3208 Engine. Applied Physics and Engineering Division of B.C. Research in Vancouver, B.C., Canada. Prepared in draft form for the Canadian Energy, Mines and Resources Transportation Energy Division in Ottawa, Ontario. File No. 6-09-623. April, 1987.
- 20) "Experiences with CNG and LPG Operated Heavy Duty Vehicles With Emphasis on US HD Diesel Emission Standards." Jouke van der Weide, Jan Jeen Seppen, Joep A.N. van Ling and Henk J. Dekker. Presented at the International Fuels and Lubricants Meeting and Exposition in Portland, Oregon during October 10-13, 1988. SAE Publication #881657.
- 21) "Methanol Supply and Demand Issues from a California Perspective." K. Koyama, K.D. Smith, L. Ghaffari of the California Energy Commission and C. Moyer from the Acurex Corporation. Presented at the 1987 World Methanol Conference in San Francisco, California during December 1-3, 1987.
- 22) "Methanol vs. Natural Gas Vehicles: A Comparison of Resource Supply, Performance, Emissions, Fuel Storage, Safety, Costs, and Transitions." Mark A. DeLuchi, Robert A. Johnston and Daniel Sperling. Presented at the International Fuels and Lubricants Meeting and Exposition in Portland, Oregon during October 10-13, 1988. SAE Publication #881656.
- 23) "Natural Gas As an Alternative Vehicular Fuel: The Role of GRI's Research Program." Bruce A. Hedman of the Gas Research Institute in Chicago, Illinois. Presented at the Air and Waste Management Association's 82nd Annual Meeting and Exhibition at Anaheim, California during June 25-30, 1989. Publication #89-63B.2
- 24) Natural Gas In a D.I. Diesel Engine: A Comparison of Two Different Ways. Qu Jun-ming, Erik Kofoed and Spencer C. Sorenson. Laboratoriet For Energiteknik, Publication #RE87-1. 1987.
- 25) "Offshore Operations NO_x Control Development Program." Report prepared by the Scientific Services Program of Arthur D. Little, Inc. for the U.S. Department of Interior Minerals Management Service. December 1988.

- 26) "Performance and Emission Characteristics of the Deutz Glow Plug Assisted Heavy-Duty Methanol Engine." Dr. Cornelis Havenith, Heinz Kuepper and Ulrich Hilger. Presented at the Truck and Bus Meeting in Dearborn, Michigan during November 16-19, 1987. SAE Publication #872245.
- 27) "Performance and Emissions of Propane, Natural Gas, and Methanol Fuelled Bus Engines." W. A. Goetz, D. Petherick and T. Topaloglu. Presented at the International Congress and Exposition in Detroit, Michigan during February 29 - March 4, 1988. SAE Publication #880494.